The Ecology and Acoustic Behavior of Minke Whales in the Hawaiian and Pacific Islands

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LONG-TERM GOALS

The long-term goals of this research project are to develop and use methods to collect passive acoustic data that will improve our understanding of ecology and behavior of minke whales (*Balaenoptera acutorostrata*) in their presumed breeding habitats around the Hawaiian Islands and other subtropical Pacific areas. Ultimately, the new information and methods resulting from this project will provide new research tools and a better understanding of biology of minke whales so that more effective management and conservation practices can be implemented.

OBJECTIVES

The overall objectives were to use passive acoustic methods to investigate minke whale acoustic ecology and behavior in sub-tropical North Pacific islands areas by monitoring a unique vocalization that they produce known as a 'boing'. Our main field research objectives were to collect data simultaneously from two different passive acoustic systems: 1) a quiet research vessel towing a hydrophone array, and; 2) a U.S. Navy fixed hydrophone array located along the seafloor in the study site. In addition we used towed hydrophone array data and autonomous recorder data collected by us and collaborators in other island areas of the north Pacific to compare with. Secondary goals were to develop and use new methods to review and analyze acoustic data collected from towed hydrophone arrays and autonomous recorder data.

Our specific objectives were to use vessel-based passive acoustic methods to collect data that would be used to estimate the density and abundance of minke whales at our study site. A second objective was to investigate minke whale acoustic behaviors (including the effects of noise from our survey vessel on the acoustic behavior of minke whales) so that biases in the analysis results could be assessed. The third objective was to investigate the population structure of minke whales by measuring and comparing acoustic characteristics of boings recorded at our main study area in the Hawaiian Islands to other regions such as the Marianas, Wake and Midway Islands.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2011		**00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The Ecology and Acoustic Behavior of Minke Whales in the Hawaiian and Pacific Islands	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Bio-Waves Inc,517 Cornish Dr,Encinitas,CA,92024**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**9**	

APPROACH

This effort is a partnership with several researchers and institutions working on related efforts. These include Stephen Martin (SPAWAR), Len Thomas and Vincent Janik (Univ. of St. Andrews) and Eva Nosal (Univ. of Hawaii-SOEST). Other (unfunded) collaborators include John Hildebrand and Amanda Cummings (SIO-Applied Physics Lab). Bio-Waves was responsible for vessel-based surveys and validation efforts as well as all data analysis of towed array data.

We conducted combined visual and acoustic line-transect surveys of minke whales at our study site off of Kauai. The study site is a large (~ 1900 km^2) rectangular shaped region that includes areas of deep (up 4500 m) ocean waters located to the northwest of the island of Kauai (Fig. 1). This study area was chosen because it is outfitted with several sea-floor hydrophone arrays that are part of the Pacific Missile Range Facility (PMRF). During the survey effort, acoustic data were acquired and recorded (by S. Martin) from 15 to 19 hydrophones from the BSURE seafloor array. These data were post-processed using Matlab scripts developed (by S. Martin) to localize and estimate the density of boings produced by minke whales.

Visual and acoustic line-transect surveys conducted from an acoustically quiet 87 ft. motor-sailing research vessel the R/V Dariabar. A two-element towed hydrophone array was deployed throughout the survey. Boings from minke whales were monitored and processed in real-time using ISHMAEL, Pamguard and Whaletrack II software for localization, plotting, and data-logging. Visual surveys were conducted whenever conditions allowed the use of standard line-transect protocols. All acoustic data were recorded to hard drives for post-processing and archival purposes.

Localizations of minke whales were processed in real-time during towed hydrophone array surveys. These data will be post-processed using a custom developed program called 'Boinger' developed by St Andrews and Bio-Waves Inc (for details see year-end report by Thomas and Janik, St Andrews University). Boinger was developed to conduct a detailed review and re-analysis the towed array acoustic localization data. This program uses .wav files and Whaletrack II database from the towed array survey as data inputs. Data outputs include localization times, geographic locations and perpendicular distances from the survey track-line. Clips of boings and detailed measurements of boing characteristics are also provided for identification of individuals and further analysis of boings.

The boinger outputs and other data will be imported into the program DISTANCE to estimate the density of calling animals using distance-sampling analysis methods (Thomas and Janik, 2010). These density estimates will be used to calculate average boing production rates of minke whales in the study area which are needed for the spatially explicit capture-recapture methods that are being developed as part of the related DECAF effort (Marques et al. 2010).

Acoustic characteristics of boings recorded during the 2009 and 2010 field season were compared to boings recorded in the Northern Marianas Islands (via towed array surveys), Midway Islands and Wake Island (both from SIO's HARP data). Boings were clipped and compiled for semi-automated measurement of over 45 variables using the Matlab based program Osprey (courtesy of D. Mellinger, OSU). Measurements from the four areas were compared using a Random Forest tree analyses. This robust non-parametric statistical analysis allows a simple and intuitive method to compare and identify features of boings that are important in elucidating differences among the samples from these areas.

WORK COMPLETED

We conducted vessel based line-transect surveys over 4 weeks in spring 2010. A total of 13 days of survey effort consisted of four complete surveys for a total of 1520 km of line-transect were completed, averaging 380 km for each survey (for details see Norris 2010 annual report). These data were compiled and formatted for input into the program Boinger. Automatic detectors in Ishmael (provided courtesy of Dave Mellinger and S. Martin) were run on the acoustic data. Acoustic detections of minke whales that were made in the field, and those resulting from the Ishmael automatic detection results, are now being reviewed and re-analyzed using the program Boinger. Detailed measurements of boings were made in late 2010 and early 2011 were used in the random forest geographic analysis of boings that was conducted in summer 2011.

Presentations, Conferences and Workshops Attended.

Results from various aspects of this project were presented by Tom Norris at three meeting since the last annual report: 1) an oral presentation at the 2nd Pan-American/Iberian Meeting on Acoustics**,** Cancun, Mexico 15-19 November 2010; 2) an poster presentation at the Animal Communication conference held at Cornell University, Ithaca, NY, 2-5 August; and, 3) an oral presentation about the towed array data review and analysis program 'Boinger' at Density, Localization and Classification workshop, Mt. Hood, Oregon 22-25 August 2011. Mr. Norris also attended the workshops at the Cornell and Mt. Hood conferences. For the remainder of the year, an oral presentation authored by Mr. Norris was accepted for the Acoustic Ecology Session at the ASA San Diego meeting in early November. Finally, a poster presentation has been accepted for and the Society for Marine Mammalogy meeting in Tampa Bay, Florida in late November. Mr. Norris is planning to attend several workshops at this meeting.

RESULTS

Line-transect/Density Estimation

Over 1600 minke whale boings were detected during on-effort towed-array acoustic surveys (Fig. 1). Bearings were calculated for many of these boings in-near real-time during field operations. These bearings resulted in preliminary localizations for just fewer than 50 minke whales (Fig. 2). A preliminary density estimate was calculated from these data (Thomas and Janik 2010 annual report for results). However, we were concerned about the quality of the localizations used, as there were processed in real-time which often results in many uncertainties and errors which cannot be easily assessed during field operations. Therefore, the acoustic data are being reviewed and re-analyzed to improve quality control and provide more precise perpendicular distances to the track-line. The program 'Boinger' developed this year is being used for this re-analysis. These data will be used for estimating density using modified line-transect methods with the program 'Distance'. The resulting density estimate will be used to determine an average boing rate per animal for use in the DECAF/SECR density estimation effort by our collaborators.

Effects of Vessel Noise on Vocalization Rates

No additional work has been conducted on this topic since the last report.

Boing Analysis and Geographic Comparisons

Comparisons of boing characteristics measured from island of Kauai, the Mariana Islands and Midway Island were initially conducted in 2010 using CART, T-tests, and ANOVA's (the latter was sample obtained from HARP data courtesy of John Hildebrand/SIO). Boings were clipped from recordings

and 48 variables were measured semi-automatically using the Matlab bio-acoustic analysis program 'Osprey.' Results of these preliminary analyses indicated that there were differences in boings among these some of these areas that could be predicted base on the location of the recording (see Norris 2010 year end report). After reviewing these preliminary results further, we decided that Random Forest analysis would be more effective than the CART analysis used in 2010. In addition, we added samples obtained from HARP data (also provided by SIO) collected from Wake Island, which is located at an intermediate longitude between Midway and the Mariana Islands. We used selective criteria for determining independence of samples as well as randomly sub-sampling data to provide equal sample sizes of approximately 60 boings from each area. We investigated the relative importance of the 48 variables used in the initial analysis (Fig. 3). Results thus far indicate that boings from the four disparate geographic regions (Marianas, Hawaii, Wake or Midway) are distinct from one another with the Random Forest analysis correctly classifying over 70% of boings to the correct region (Table 1). Boings recorded from Kauai were the most likely to be confused with boings recorded from the Mariana Islands) whereas boings from Wake had the highest classification scores, indicating these were the most distinctive.

There were some confounding factors in this analysis due to the fact that some areas used different recording methods (e.g. towed hydrophone arrays for Kauai and the Mariana Islands versus autonomous bottom recorders for Midway and Wake Island). In general, boings recorded from areas using the same recording methods were more likely to be erroneously attributed to an area using those methods (except for Wake Island, which was most often confused with the Mariana Islands, the closest of the three other locations). We performed a random forest analysis to evaluate how well boings could be classified to recording method rather than geographic region. The results of this analysis showed that 84% of boings recorded using the autonomous recorder and 82% of boings recorded using the towed array could be classified correctly to the recording method. This suggests that recording method may have an effect on determining which boing characteristics were most important in the classification models. We believe that that the higher misclassification rates between the Mariana Islands and Kauai are likely due to the similar recording methods used. However, this result could also be due to the closer longitudinal proximity of some of the areas (e.g. Midway and Wake Islands). We are currently examining these possibilities further. Regardless of these confounding issues, the results appear promising that we will be able to classify boings to their respective geographic locations.

Fast Research Vessel Validation work
No additional work was conducted on this topic since the last report.

IMPACT / APPLCIATIONS

Acoustic based line-transect surveys will be used to derive density estimates of calling minke whales in the Kauai study area. Obtaining an accurate estimate of density of calling animals is important because to date, there are no estimates of minke whale abundance in the Hawaiian or other Pacific Island regions. This is not due to a lack of effort, but rather due to a paucity of visual sightings. Furthermore, we are developing software tools to semi-automate this analysis. We are already using products and new analytical methods derived this research effort to estimate densities of calling minke whales in other areas for the Navy (e.g. the Mariana Islands range complex Operating Area). Density information is important for effective management and mitigation of human activities on this federally protected species of marine mammal. In addition, our results will be used as inputs in a related effort that is using seafloor hydrophones to estimate densities of minke whales from boings using SECR methods. Both of these efforts will provide new information but also new methods for estimating

abundances of a species that is rarely sighted. It is likely that these techniques can be applied to other species and areas.

Our preliminary results on the acoustic behavior of minke whales are significant because they provide important insights into the acoustic behaviors and important characteristics of minke whale calls. Acoustic characteristics of minke whale boings are poorly understood, especially for populations in the North Pacific. We and our collaborators have determined that there are specific acoustic characteristics of the boings that can be used to successfully classify boings among four disparate areas sampled. These results are an indication that some level of population structure exists in these areas. The findings should help to further investigate population structure in these regions. We are also investigating what the effects of different sensors and recording platforms have on a host measured variables from recordings of boings which is important for designing and analyzing results of future studies. Results from these comparisons can be used to elucidate population structure of minke whales in the North Pacific and potentially allow examination of the relative degree of mixing of minke whales in these disparate areas

In summary results of our efforts are providing important information about the distribution, abundance, population structure and acoustic behavior of a vocally active species that is difficult if not impossible to study visually in the Central and western subtropical Pacific. The analytical tools we are developing can be applied to other data that have been or are being collected to provide important information on the abundance, distribution and population structure of minke whales and other species with similar acoustic behaviors.

RELATED PROJECTS

Related projects are being conducted by Len Thomas, Vincent Janik, and Steve Martin. These include the Density Estimation for Cetaceans from passive Acoustic Fixed sensors (DECAF) project that was conducted simultaneously with our effort. These projects are using density estimates derived from our effort to calculate average boing (cue) rate so that estimates of minke whale densities can be derived from seafloor and autonomous hydrophones.

Other related projects include efforts to use acoustic data from seafloor arrays to localize and track minke whales using boings recorded from the PMRF BSURE array. These two projects are being conducted by Stephen Martin (SPAWAR-San Diego, CA) and Eva Nosal (University of Hawaii-SOEST. S. Martin collected acoustic data from the PMRF hydrophone array concurrently with our field effort and calculated locations based on a 2-D approach. Dr. Nosal used XBT data collected from our survey vessel in 2009 as sound speed profile inputs to develop propagation model-based 3-D localization approach (see year end report by Nosal for details). We are providing localization data from line transect survey data to compare to those localized from the seafloor array data for validation and other work as needed by these related efforts. Towed array acoustic data from the Mariana Islands and Sea Turtles and Cetacean Survey (MISTCS) is currently being analyzed for several species of marine mammals, including minke whales. Tools from developed from the ONR effort are already being used to facilitate this analysis and provide detection functions and possibly density estimates for some species.

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Table 1. Correct classification scores (in bold) of actual versus predicted geographic locations. Towed hydrophone array recordings are denoted with '+' after the locations. Autonomous bottom recorders are denoted with '*' after location. Highest error rates per location are in red.

Percentages

actual	**predicted**				
	Mariana+	**Wake***	**Midway***	**Kauai+**	**n**
Mariana+	**79.7**	5.1	6.8	*8.5*	59
Wake*	10.2	**84.7**	3.4	1.7	59
Ladd*	5.1	10.2	**79.7**	5.1	59
Kauai +	15.3	8.5	5.1	**71.2**	59

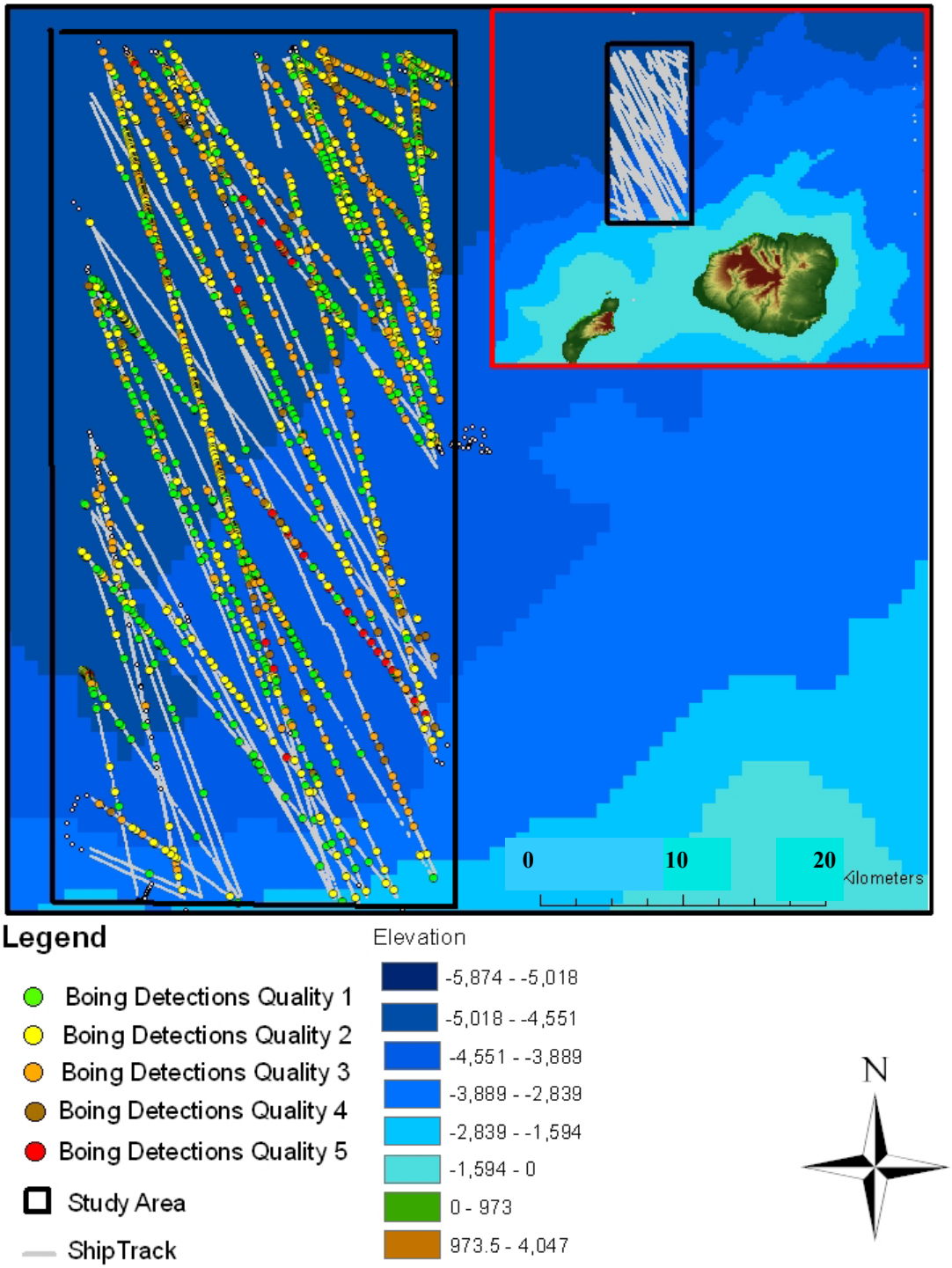

Figure 1. Study area (~ 1900 km^2) off Kauai with acoustic line-transects completed during the 13 days of effort (128 hours totaling 1500 km). Positions where boings were detected (plotted on the trackline) are indicted with small circles. Colors indicate relative intensity/quality (1 = low ; 5 = high).

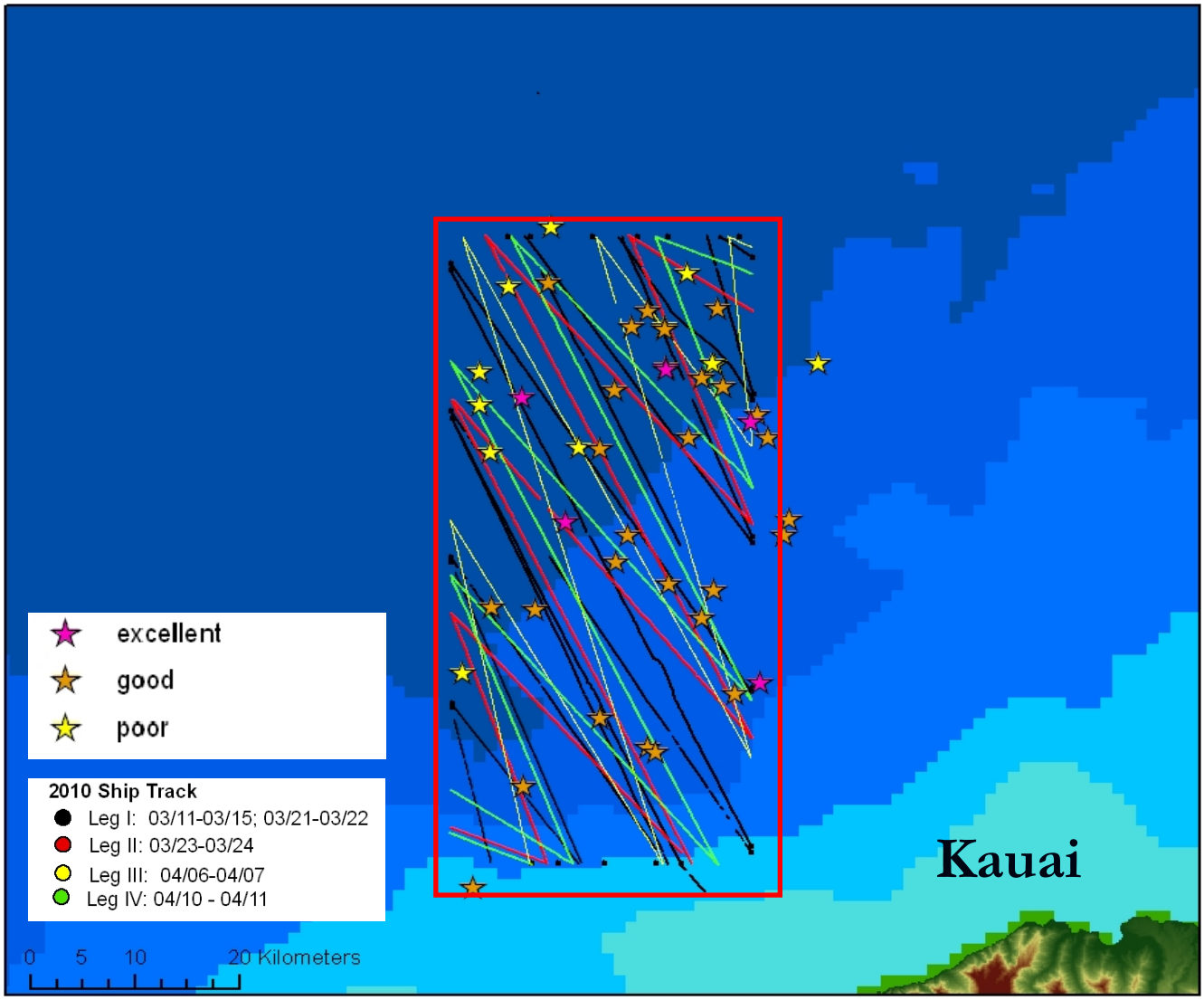

Figure 2. Real-time localizations (stars) that were processed during the field effort. These data are being re-analyzed using the program Boinger, that was developed in spring/summer 2011 to review towed array data. Outputs from Boinger will be used as inputs into the program DISTANCE for estimating densities of calling minke whales.

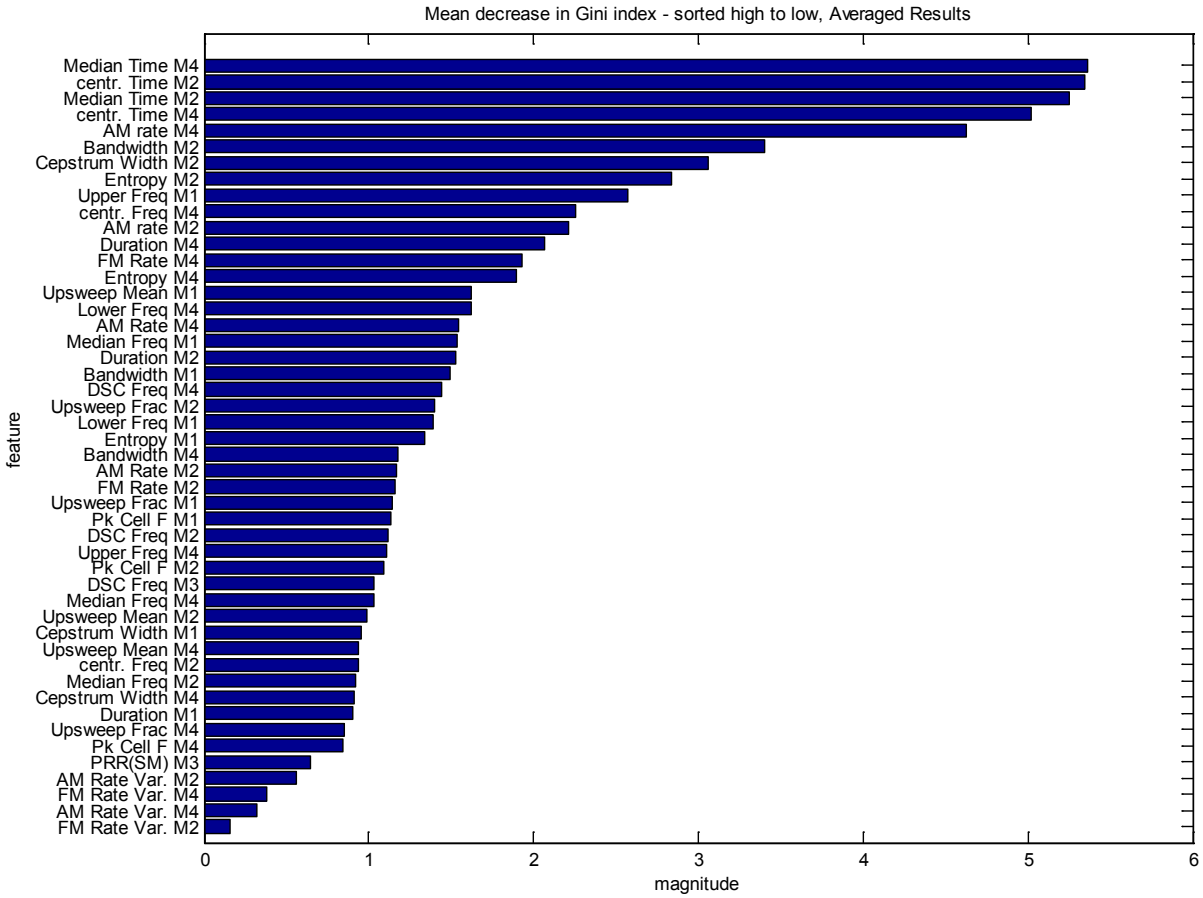

Figure 3. Relative variable importance plot of 48 variables measured with Osprey and used in the Random Forest tree analysis.